ANNUAL REPORT

I. Principal Investigator: William M. Frank

ONR Grant No. N00014-92-J-1069
"The Vertical Distribution of Heating in the Tropical Atmosphere"
1 OCT 1991 - 30 SEP 1994

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II. Summary of Completed Work:

This grant supported research in two areas. The primary goal of the work was to plan and participate in the TOGA-COARE (Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Experiment) program and to analyze large-scale heat and moisture budgets with the data from that experiment. The second major goal was to analyze relationships between large-scale tropical circulations and tropical cyclone intensity changes in the Northwest Pacific. Research has gone very well in both areas.

The TOGA-COARE IOP (Intensive Observational Period) occurred from 1 NOV 1992 - 31 MAR 1993. During most of that period one of the graduate students supported by the grant was located at BMRC (Bureau of Meteorology Research Centre) in Melbourne, Australia acquiring and processing data from the BMRC operational data set. The PI also visited both Melbourne and Townsville, Australia for a few weeks during the field program. The data acquired through BMRC were combined with data from numerous other sources that were obtained later. These included late-reporting surface observations, satellite imagery, data from the integrated sounding systems (ISS) and sea surface temperatures, obtained from the data archives at the National Center for Atmospheric Research (NCAR). The data were subjected to error checking procedures both before and after budgets were computed to remove obviously bad data points.

Sensible heat and moisture budgets were computed for a variety of polygons as shown in Fig. 1. The arrays and subarrays were designed to permit optimum use of the line-integral technique for computing budgets. This procedure was chosen to preserve the divergent component of the wind in the analysis scheme. Budgets were computed for daily-averaged values of the winds, temperatures and moistures.

The goal of the work was to determine the important vertical distributions of subgrid-scale convective processes as residuals in the budget equations and to relate variations in

these distributions to observable large-scale features. The arrays cover a variety of maritime weather regimes as well as the island of Papua New Guinea. Examples of profiles of Q (diagnosed subgrid-scale diabatic heating) averaged over the 120 days of the IOP are shown in Fig. 2. The profiles in all areas look remarkably similar. Mean rainfall estimated from the budgets agrees well with estimates from gages and radar in the Intensive Flux Array (IFA) region, where the most extensive array of instrumentation was employed, lending confidence to the accuracy of the budgets.

The diabatic heating estimates were correlated with large-scale meteorological variables and sea surface temperatures, and the heating profiles were subjected to Empirical Orthogonal Function (EOF) analyses to separate significant modes. In all regions the net heating was dominated by one mode that varied little from region to region or with time.

Variations in surface fluxes appear to be dominated by variations in the low-level wind fields. Analyses of relationships between diagnosed heating and large-scale circulation features confirm that rainfall occurs during periods of strong low-level wind speeds. However, the winds tend to be coincident with or slightly lagging the rain, indicating that the rain does not occur in response to previous wind-induced surface energy fluxes. Further, the relationships between surface fluxes and the precipitation vary spatially, with fluxes and rainfall being more closely coupled south of the equator than in the more northerly regions. Thus, the large-scale equilibrium structure is more complicated than can be explained by a simple surface flux model. A major goal of the current proposal is to explore in detail the relationships between the large-scale flow, surface winds and fluxes, and synoptic-scale weather systems.

The TCM-90 research focussed on the relationships between upper level circulation features and changes in the structure and intensity of five typhoons that occurred during the two-month field portion of that program. Each of these five storms experienced at least one period during which there was an inward-propagating region of enhanced eddy angular momentum flux in the upper levels. These regions of enhanced momentum fluxes were accompanied by increased mid-level inflow and upper-level outflow. A schematic diagram of this process based on the five storms is shown in Fig. 3.

The storms tended to undergo a drop in central pressure about 30 hours after the region of enhanced inward momentum flux reached 10 degrees radius and within 12 hours of the time that the flux maxima appeared to reach three degrees radius. It is hypothesized that the momentum fluxes unbalance the flow leading to enhanced upward vertical motion in the core. This then leads to contraction and intensification of the storm core. Since the momentum flux anomalies occurred in all five storms studied, and since they begin as large-scale features in the upper troposphere, it should be possible to develop predictive techniques relating the large-scale structure of the upper-level circulation of a tropical cyclone to subsequent intensity changes.

III. Statistical Information

Publications:

Briegel, L.M. and W.M. Frank, 1994: the role of large-scale circulations in Western pacific tropical cyclogenesis. To be submitted to Mon. Wea. Rev.

Briegel, L.M., 1993: The role of the large-scale flow in tropical cyclogenesis in the western pacific ocean, M.S. thesis, The Pennsylvania State University, 110 pp.

Briegel, L.M., 1993: An observational study of tropical cyclogenesis in the western pacific ocean. 20th Conference on Hurricanes and Tropical Meteoroogy, San Antonio, Texas, 10-14 May 1993, 397-400.

Frank, W.M, J.L. McBride and H. Wang, 1994: Large-scale heat and moisture budgets during TOGA-COARE. To be submitted to J. Atmos. Sci.

Frank, W.M. and J.L. McBride, 1993: Relationships between convection and vertical stability in the tropical atmosphere. 20th Conference on Hurricanes and Tropical Meteorology, San Antonio, Texas, 10-14 May 1993, 349-352.

Marchok, T.P., 1994: The role of upper-level eddy angular momentum fluxes in the intensification of five typhoons during TCM-90. M.S. thesis, The Pennsylvania STate University, 169 pp.

McBride, J.L., and W.M. Frank, 1994: The vertical stratification of the tropical atmosphere in the presence of deep convection. To be submitted to: J. Atmos. Sci.

Graduate Students

Ms. Lisa Briegel (female): Completed MS degree May 1993. Currently a PhD student. Passed candidacy exam.

Mr. Timothy Marchok: Completed MS degree Fall 1994.

Mr. Houjun Wang: PhD student. Passed candidacy exam.

Mr. John Wozniak: Mr. Wozniak is supported by an ONR fellowship and receives some research support from this grant. PhD student. Passed candidacy exam.

Invited Presentations: Four oral presentations on the TOGA-COARE results at the TOGA-COARE Workshop, Toulouse, France, August 1994.

Presented invited lectures on cumulus parameterization, NCAR, UCAR Summer Colloquium on Clouds and Climate, July 1993.

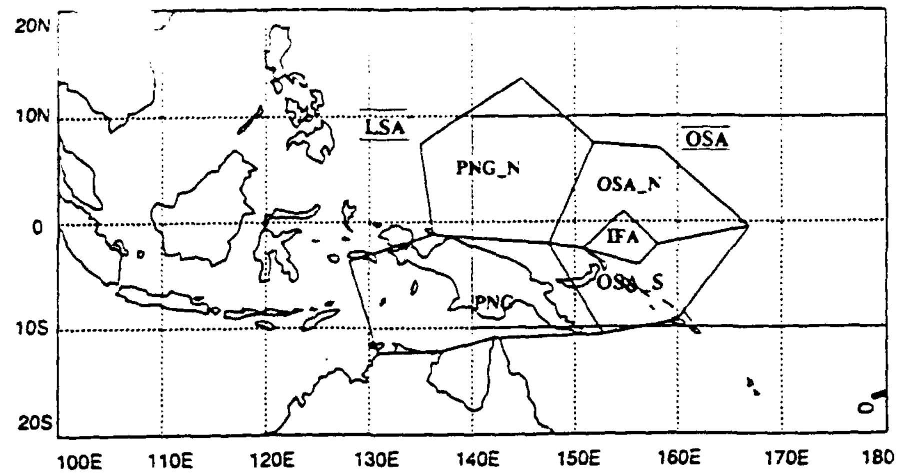

Fig. 1. The seven arrays used in the budget analyses of TOGA-COARE IOP data. Five of the polygonal arrays are labeled within their boundaries (PNG - Papua New Guinea, PNG-N - area north of PNG, IFA - Intensive Flux Array, OSA-N - northern portion of OSA excluding the IFA, and OSA-S southern portion of the OSA including the IFA). The sixth array is the entire area and is referred to as the LSA (Large-Scale Array). The seventh is the large roughly hexagonal area including both the OSA-N and OSA-S and is referred to as the OSA (Outer Sounding Array). There is a rawinsonde station at each intersection on the perimeters of the arrays.

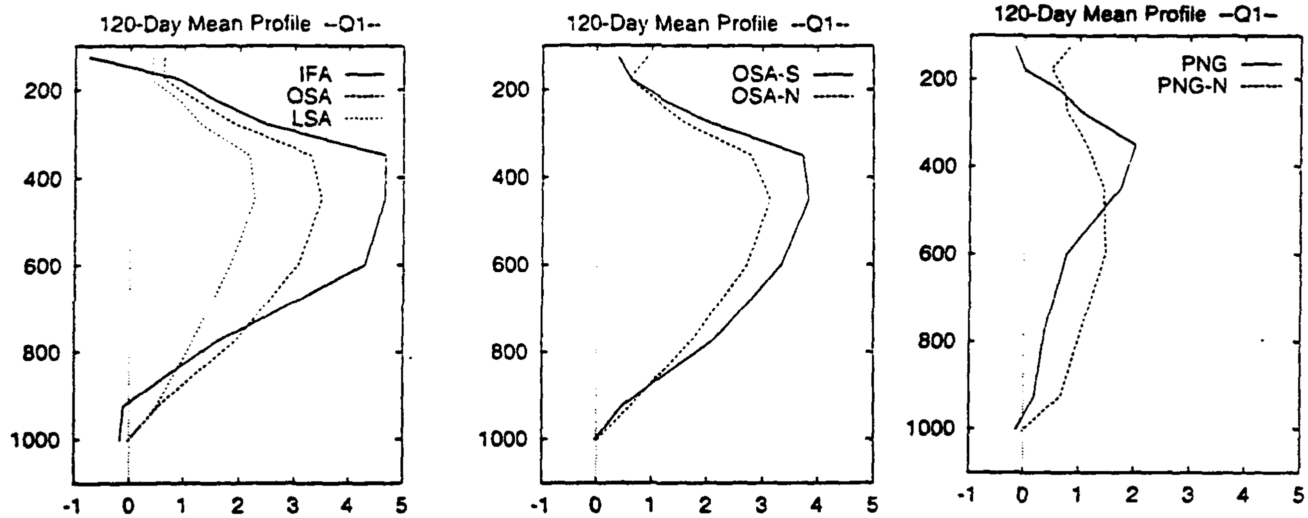

Fig. 2. Vertical distribution of net diabatic heating (Q - primarily latent heat release plus radiation) for the arrays shown in Fig. 1, averaged over the 120 days of the IOP.

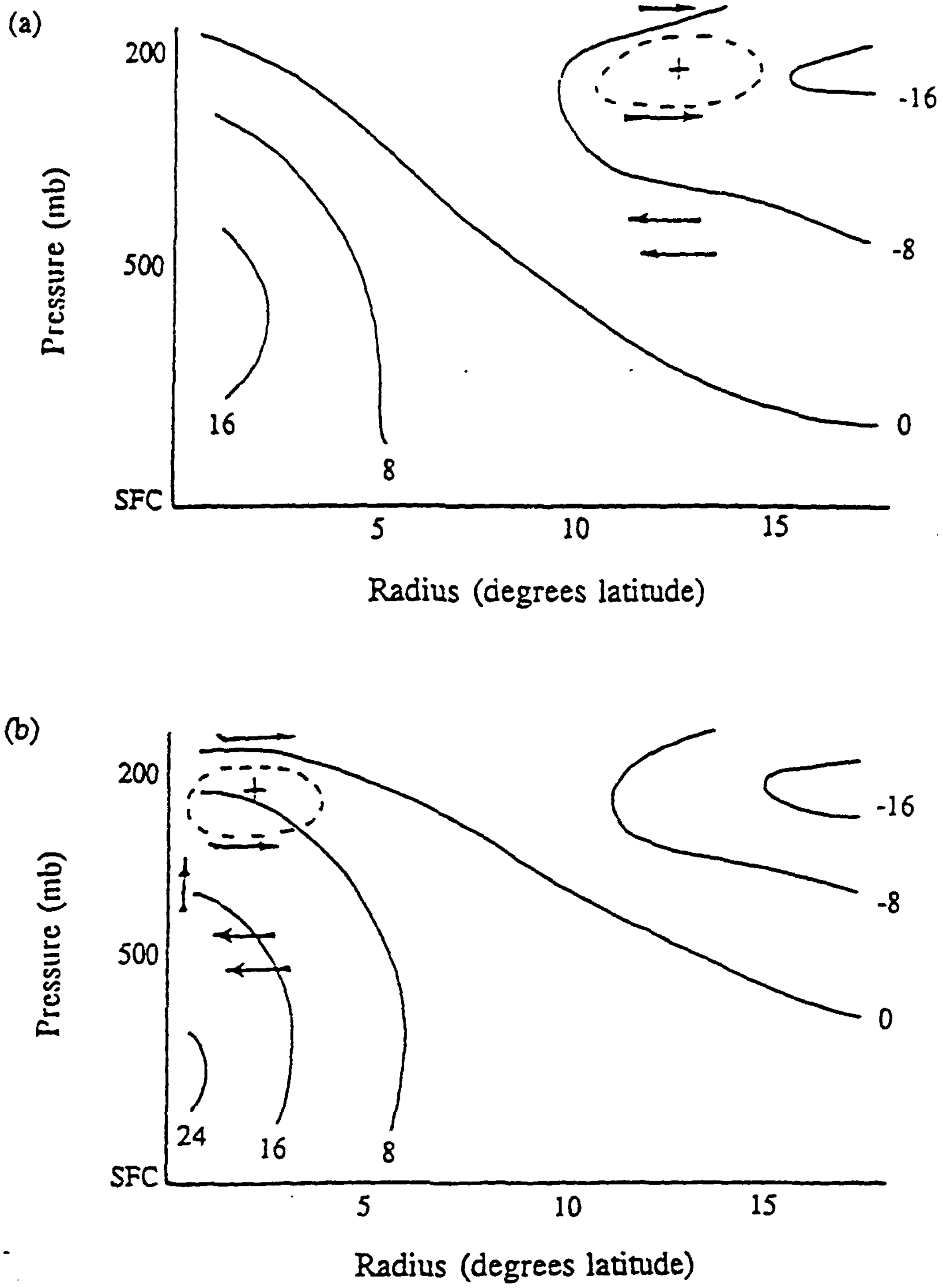

Fig. 3 Schematic diagram of the inward propagation of a region of upper-level eddy angular momentum flux (dashed contours), and the accompanying secondary circulation (shown by the arrows). Solid lines are mean tangential winds in m/s. The upper diagram shows the initial time at which the momentum flux anomaly is observed, and the lower panel is at a time 24h later. All five of the TCM-90 storms exhibited such anomalies, and in four of the five, the intensity dropped significantly at about the time the anomaly was estimated to reach the storm's center.